Watch Your Step: Impacts of Trampling on a Rocky Shoreline of San Juan Island, Washington

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Abstract
Rocky intertidal habitat at San Juan County Park, Washington, was experimentally trampled to assess risks of human visitation to ecological communities. For six weeks in spring, six 5-m vertical transects were subjected to augmented trampling (250 steps, three times a week) in the zone dominated by the brown alga *Fucus gardneri*, and six additional transects received low levels of trampling from park visitors. Densities of five taxa were recorded throughout this period and for three months thereafter. Repeated observations were made at three tidal elevations along each transect using fixed quadrats (20 x 20 cm). Trampling reduced cover of *Fucus* to 30% of its original value within 6 weeks, and cover remained lower in trampled than control quadrats throughout the "recovery" period. Trampling also resulted in a short-term decline in taxon richness, from an average of 8 to 7 taxa per quadrat. The turf-like alga *Endocladia muricata* did not respond to trampling, nor did barnacles. Mobile gastropods (limpets and whelks) also remained similar in trampled and control areas. Bare space showed a delayed response to trampling, increasing one month after trampling ceased. This study highlights a management challenge of protecting natural habitats in parks and reserves while still encouraging public access and appreciation.

Introduction
Rocky intertidal communities are sensitive to the effects of anthropogenic disturbance. Common forms of disturbance range from indirect (often chronic) agents, such as sewage and industrial effluent (Littler and Murray 1975), to more direct agents, such as harvesting and development (Duran and Castilla 1989; Underwood and Kennelly 1990; Povey and Keough 1991; Kingsford and others 1991). These impacts have led to decreased biomass, decreased species richness and shifts in community composition worldwide (Littler and Murray 1975; Duran and Castilla 1989; Keough and others 1993, Lasiak 1998).

To prevent widespread degradation and habitat loss, some intertidal shorelines have been designated as parks and reserves. Parks and reserves protect shorelines from commercial or development impacts, but these areas also become popular recreational destinations, leading to increased recreational pressure. Recreational activities include general exploration, specimen or food gathering, educational field trips, and fishing. Such activities are not benign: collecting, constant foot traffic, and exploratory manipulation of rocks affect the intertidal environment (Sousa 1979; Murray and others 1999).

Today parks and reserves face the challenge of achieving goals of public accessibility and environmental preservation. Effective management requires a detailed understanding of ecological impacts resulting from anthropogenic disturbances as well as a detailed knowledge of the system itself.

Annually, city-dwellers, adventurers, and pleasure seekers converge on San Juan Island with its allure of quiet beaches, charismatic fauna, and unique environment. While the tourist draw brings economic benefits to the community, there is growing concern for the protection and preservation of the island's many beaches and the organisms living there.

To understand how island visitors interact with the environment, we surveyed 107 visitors at 4 San Juan Island parks in the spring of 2000. Of those surveyed, 50% were not Washington state residents. Few visitors reported visiting parks specifically for intertidal exploration. Most visited for general exploration (camping, kayaking, picnicking), and 37% were whale watching. However 85% of respondents reported that they had walked along the intertidal shoreline. Only 60% of the people surveyed could name more than one organism found living in the intertidal habitat, with barnacles and snails being the most common answers.

While parks provide areas for people to enjoy nature, intense foot traffic, or trampling, through these areas may have adverse effects. Trampling, or foot traffic, will occur with all forms of intertidal access, though the intensity of trampling may vary with specific activities. Three types of impact are associated with trampling: direct mortality or dislodgment of organisms; weakening of algal holdfasts and structural damage resulting in increased vulnerability to other abiotic (e.g. desiccation) or biotic (e.g. predation) factors; and habitat loss as sessile organisms are crushed or removed (Brosnan and Crumrine 1994, Brown and Taylor 1999).

We monitored trampling effects at three intertidal heights on semi-protected shorelines of Washington dominated by the foliose alga *Fucus gardneri*. We examined responses of intertidal taxa, including foliose and turf algae and benthic invertebrates, to six weeks of augmented trampling and three months of relaxed disturbance over the course of the summer tourist season.

Methods

San Juan County Park is located on the west shoreline of San Juan Island, Washington (48°33'N, 123 °09'W). Public access is permitted year round, but intensity of human activity varies seasonally. This study was conducted over a five-month period, April to August 2000. The study area consisted of a series of rocky intertidal bluffs with western and northern facing slopes, partially accessible by foot from the upper park.

Four blocks were designated in the accessible area of the intertidal zone and four transects were placed at intervals within each block. Each transect ran perpendicular to the shore from the upper to lower limits of the *Fucus gardneri* zone. Three fixed quadrats (20 x 20 cm) were chosen in a stratified-random design along each transect (high, mid, and low portions of the zone) and marked with semi-permanent marine epoxy. Transects within each block were initially designated for augmented trampling, control, or human exclusion treatments. Augmented trampling transects were subject to regular park foot traffic as well as an additional 250 steps 3 times a week for 6 weeks, which is equivalent to moderate human use (Brosnan and Crumrine 1994). Human exclusion transects were roped off at low tide to discourage trampling during this 6-week period. Control sites were exposed to regular park foot traffic. Subsequent observations determined there was not enough foot traffic during the course of the study to warrant the human exclusion treatment. Exclusion treatments were discontinued, and exclusion and control treatments were consolidated into a single control treatment. To maintain equal sample sizes, one block containing only control transects was dropped from the study. The remaining three blocks contained two control and two augmented trampling treatments, randomly assigned, for a total of 12 transects monitored throughout the study.

For sampling, quadrats were overlaid with a grid of 100 squares, each square representing 1% of the total area. Visual estimations of percent cover were made to determine change in species abundance over time and variation among treatments. Canopy cover was measured only for *Fucus gardneri*, a foliose alga. This canopy was then moved to determine percent cover of primary (rock) space by *Endocladia muricata* (a turf alga), barnacles (*Semibalanus cariosus, Balanus glandula*), and bare space. Limpets (*Tectura scutum, Lottia strigatella, L. digitalis, L. pelta*) and whelks (*Nucella emarginata, N. lamellose*) were counted, as well as total taxon richness, within each quadrat. For total taxon richness, limpets and *Nucella* spp. were identified to species, and other taxa were identified to the lowest possible taxonomic level observer knowledge allowed. Data were recorded five times over the course of the study: prior to trampling, midway and at the end of the 6-week augmented trampling treatment, 4 and 12 weeks after augmented trampling ceased**.** Prior to analyses all data were transformed to improve normality. Percent cover data were arcsine square root transformed, and count data were natural log transformed. Repeated measures analyses of variance (RMANOVA) were used to determine if temporal trends in variables differed according to treatment and tidal elevation factors, with supplemental ANOVAs to test for treatment differences at each time point. Transect block was used as a grouping variable in all analyses. Statistical analyses were performed using Systat v 7.1 (SPSS Inc., Chicago IL).

Results

Effects of trampling were variable among organisms, both in initial impact and recovery (Tables 1-3, Figs. 1-5). Highest impacts of trampling were evident for the foliose brown alga *Fucus gardneri* (Table 1, end of paper; Fig. 1)

Canopy cover of *F. gardneri* within augmented trampling quadrats declined significantly after six weeks, from 61% to 17%, compared to 54% to 50% for control transects. Trampled and control transects remained significantly different through the recovery period.

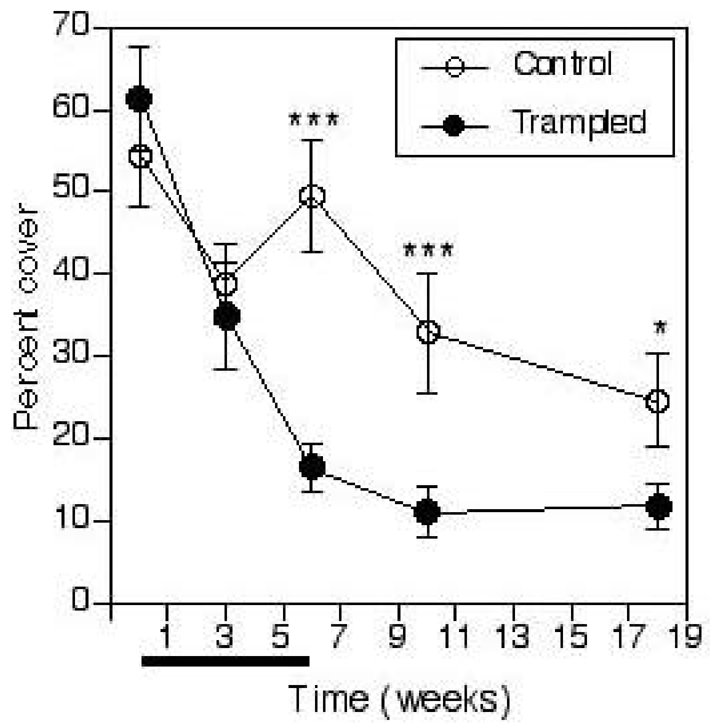

Figure 1. Canopy cover of *Fucus gardneri* from April to August 2000. Trampling occurred for the first 6 weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 18, combining three tidal elevations. Significant differences between trampled and control quadrats based on ANOVAs for each time are denoted as $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

In contrast, neither *Endocladia muricata* nor barnacle cover was significantly affected by trampling (Figs. 2, 3) Specifically, the Time x Treatment interactions in RMANOVA were not significant ($F_{4,92} = 0.95$, $P = 0.44$ and $F_{4,92} = 2.1$, $P = 0.1$, respectively). For *Endocladia*, cover was highest in high intertidal quadrats (Elevation $F_{2,92} = 3.5$, $P = 0.05$) but quite variable among replicates, which gave low power to detect a trampling effect even though average cover dropped from 15% to 5% in trampled quadrats (Fig. 2).

Results for limpets and whelks also showed no effects of trampling across time. Limpets had different patterns of temporal variation depending on tide height (Time x Elevation $F_{8,92} = 3.2$, $P = 0.003$), but trampling did not affect densities (Fig. 4))Time x Treatment $F_{4,92} = 1.9$, $P = 0.11$). *Nucella* densities were generally low and variable (Fig. 5)

The significant effect of elevation in RMANOVA arose because densities were highest low in the intertidal zone (Elevation $F_{2,92} = 15.4$, $P < 0.001$; Time x Treatment $F_{4,92} = 0.2$, $P = 0.94$). There was no significant interaction among time, treatment, and tidal elevation for any taxa, but bare space did show a three-way interaction (Table 2, end of paper).

Bare space did not increase during the time period that trampling was carried out, which reinforces our findings of no impact on primary space occupants (Fig. 6)

However, 4 weeks after trampling ended, bare space had more than doubled where previously trampled, particularly at mid and low tidal elevations.

Taxon richness declined in trampled quadrats (Table 3, end of paper; Fig. 7) from more than 8 to less than 7 taxa per quadrat during the first 6 weeks of the study, at the same time that richness in control areas increased. At the 6-week mark, richness was significantly lower where trampled than untrampled. Four weeks later, in the recovery period, richness rebounded and was not significantly different from control transects.

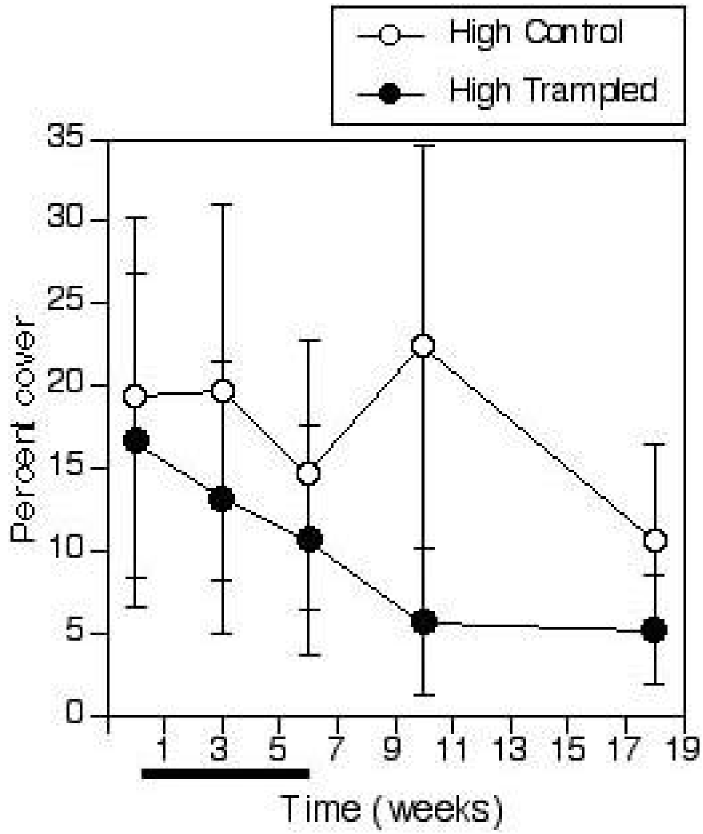

Figure 2. Cover of *Endocladia muricata* in high intertidal quadrats from April to August 2000. Trampling occurred for the first six weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 6.

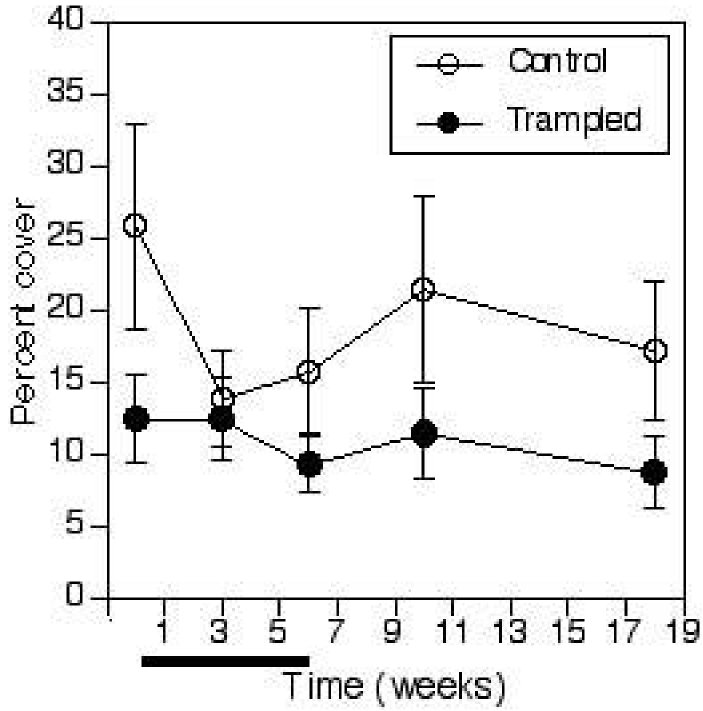

Figure 3. Cover of barnacles (*Balanus glandula*, *Chthamalus dalli*, *Semibalanus cariosus*) from April to August 2000. Trampling occurred for the first six weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 18, combining three tidal elevations.

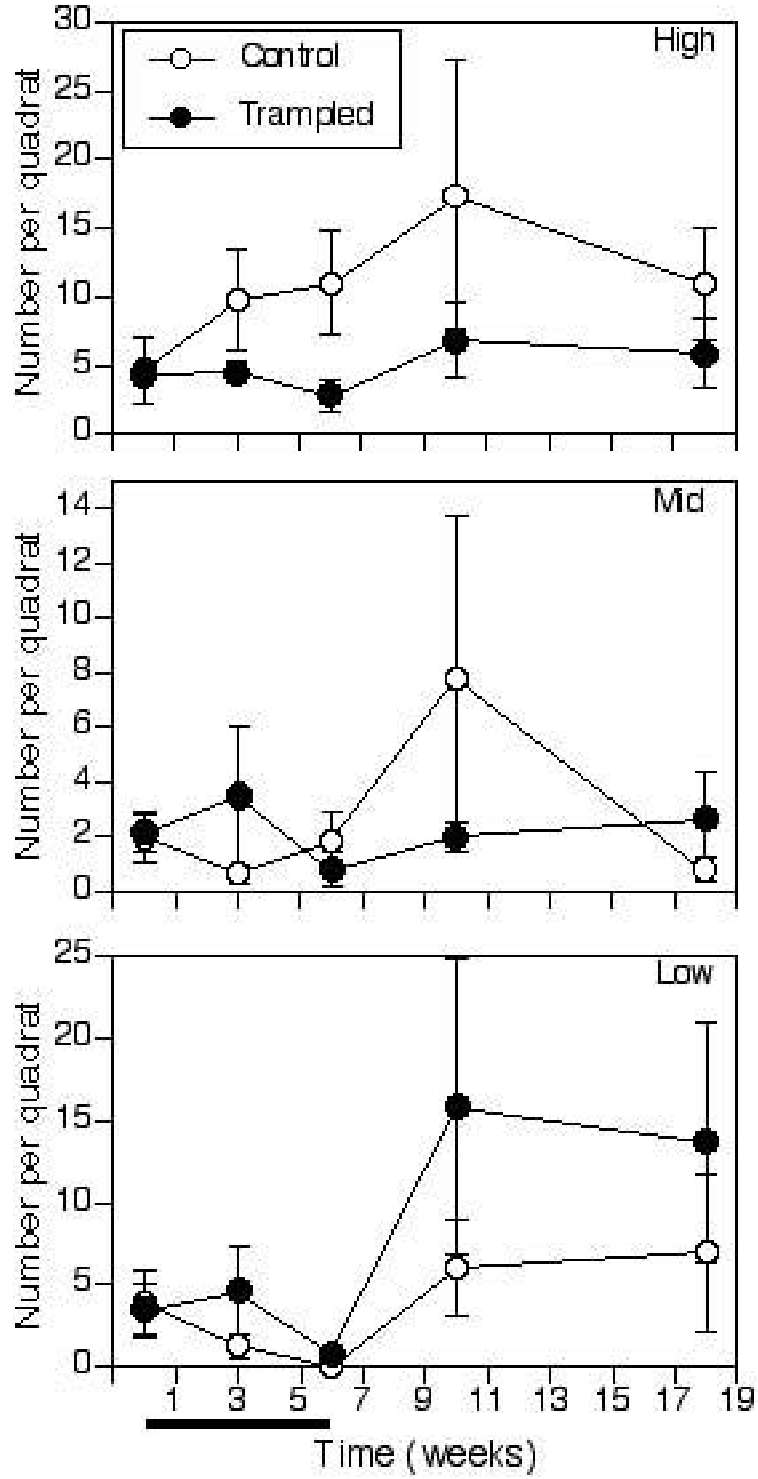

Figure 4. Number of limpets (*Lottia* spp.) in 20 x 20 cm quadrats from April to August 2000. Trampling occurred for the first 6 weeks. Statistical analyses used transformed data, but the graphs are based on raw data for ease of interpretation. Tidal elevation was significant in RMANOVA. Error bars = s.e., n = 6.

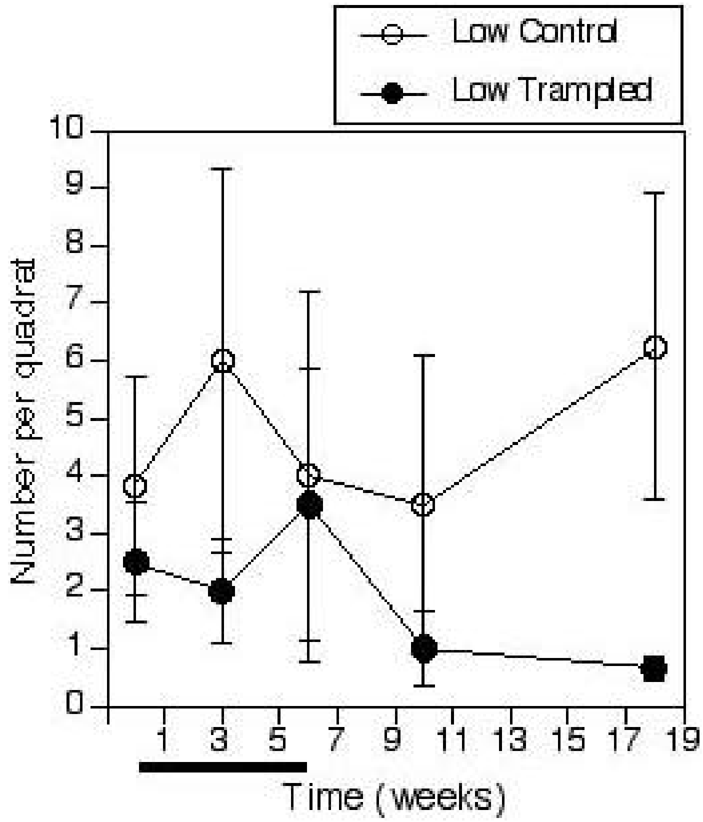

Figure 5. Number of *Nucella* spp. in 20 x 20 cm low intertidal quadrats from April to August 2000. Trampling occurred for the first 6 weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 6.

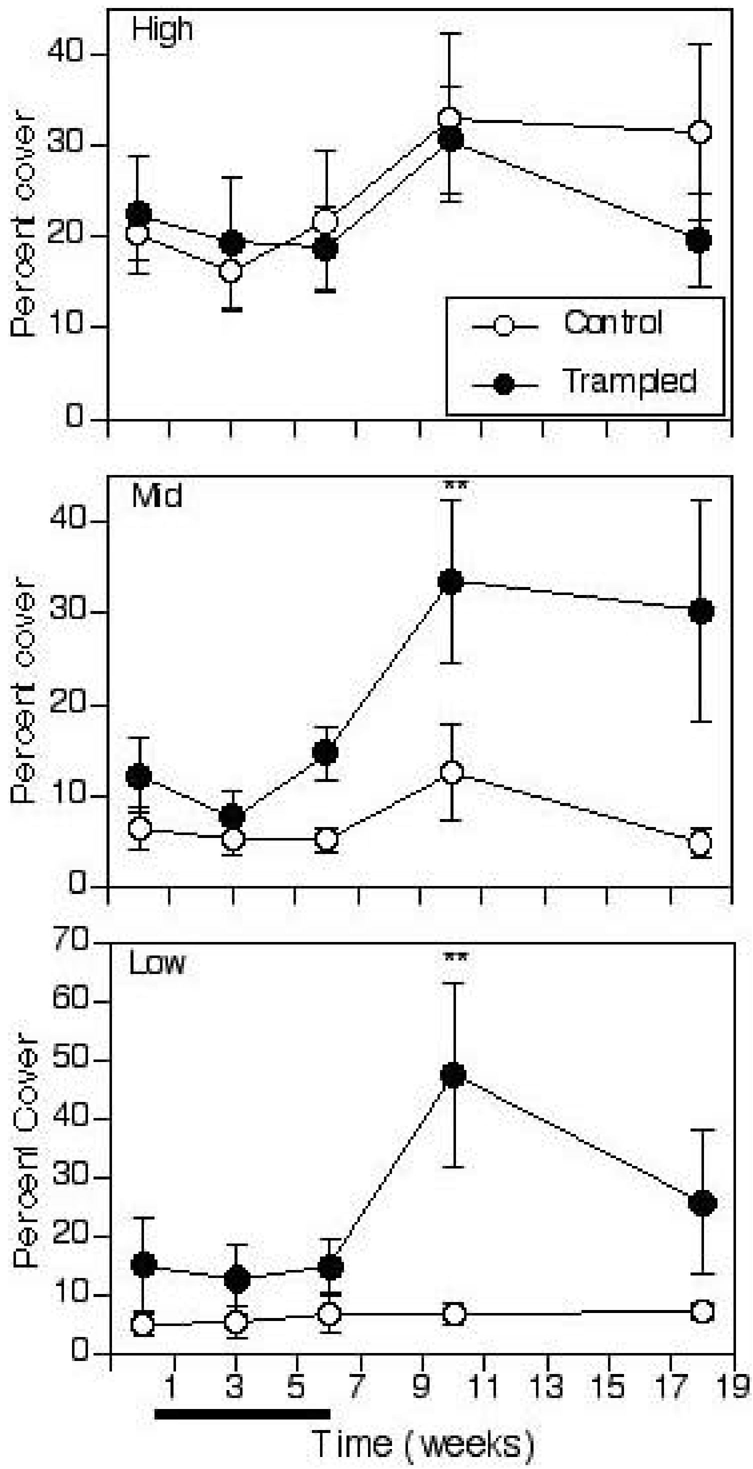

Figure 6. Cover of bare space from April to August 2000. Trampling occurred for the first 6 weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 6. Significant differences between trampled and control quadrats based on ANOVAs for each time are denoted as $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

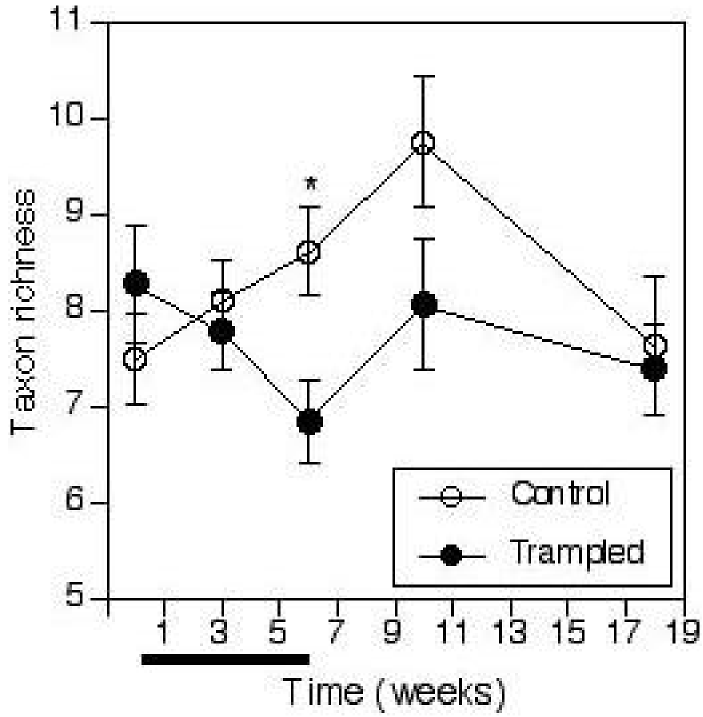

Figure 7. Taxon richness in 20 x 20 cm quadrats from April to August 2000. Trampling occurred for the first six weeks. Statistical analyses used transformed data, but the graph is based on raw data for ease of interpretation. Error bars = s.e., n = 18, combining three tidal elevations. Significant differences between trampled and control quadrats based on ANOVAs for each time are denoted as $P < 0.05$*, $P < 0.01$**, $P < 0.001$***.

Discussion

In this experiment, we augmented trampling to a moderate level over a short time period (6 weeks) in the intertidal zone. Effects were both rapid and long lasting for the canopy species, *Fucus gardneri*. Reductions in *Fucus* cover appeared after 6 weeks of trampling and continued for an additional 3 months. The foliose morphology of *Fucus* may make it particularly sensitive to direct and indirect effects of trampling. *Fucus* has a small holdfast, easily dislodged as strain increases when plants are stepped on. In wave-exposed areas, damaged holdfasts become unable to support long, heavy fronds against wave action (Brosnan and Crumrine 1994, Gaylord and others 1994). Frequent trampling can also break and crush fronds, which would reduce cover without affecting plant density. Additionally, tissue loss and structural damage to organisms remaining attached to the substrate may increase susceptibility to other abiotic and biotic factors such as desiccation and predation (Brosnan and Crumrine 1994; Schiel and Taylor 1999).

These negative impacts of trampling on canopy algae are consistent with numerous studies throughout the world. On the outer coast of Oregon, *Fucus* canopy dropped after 1 month of trampling and required three months to a year for recovery (Brosnan and Crumrine 1994). Even single trampling events can cause canopy declines. For instance, Schiel and Taylor (1998) report loss of 30% cover of fucoid canopy after 10 trampling passages on a single day. On the other hand, when studies have been carried out at multiple locations, effects of trampling often proved location-specific, such that similar levels of trampling caused canopy declines at some locations but not others (Keough and Quinn 1998).

In our study, impacts of trampling on non-canopy taxa appeared weak. *Endocladia muricata* did not significantly decline in cover in augmented trampling quadrats (Fig. 2). The turf morphology of this alga may account for its greater resistance to the pressures of trampling. *Endocladia* also grows in cracks and crevices, areas protected from foot traffic. In general, loss of canopy cover can free space for other sessile species. This free space may account for long-term increases in turf algae observed in other studies (Brosnan and Crumrine 1994; Keough and Quinn 1998), because turfs experience reduced competition for space. However, immediate impacts of trampling on turfs, as on canopy algae, can be negative as blades are removed (Schiel and Taylor 1998; Brown and Taylor 1999). Furthermore, even if cover remains unchanged, the biomass of turf algae may be reduced by trampling, as suggested by Povey and Keough (1998).

Barnacles did not respond to trampling in our study, although they began to decline after a single trampling event on the coast of Oregon (Brosnan and Crumrine 1994). Several factors differed between the two studies, most notably the temporal distribution of trampling. In Oregon, 250 steps were taken within a 20 x 20 cm quadrat once per month, and barnacles continued to decline in cover over many months. In contrast, trampling in our study occurred across a much larger area but was repeated every few days. This study may have been too short for declines to become apparent. Barnacles also have the capacity for high recruitment, which can rapidly saturate bare space. This rapid recovery may account for no difference in barnacles between areas accessible and inaccessible to humans on the California coast (Beauchamp and Gowing 1982).

Mobile gastropods also demonstrated no response to moderate, short-term and small-scale trampling. Limpets showed a trend of declining when trampled, then increased in density in both trampled and control quadrats in mid-summer (Fig. 4), possibly a consequence of recruitment. Effects of trampling on mobile species are difficult to assess in this experiment due to the small spatial scale: gastropods could have easily moved into quadrats between the time that they were trampled and resampled. Other trampling studies have also demonstrated little direct reduction of mobile gastropods (Povey and Keough 1991). Instead, over longer time periods, gastropods actually increased as canopy cover declined (Povey and Keough 1991, Keough and Quinn 1998), perhaps because reduced shading increases food supply for grazers.

Taxon richness differed between treatments at only one time point at the end of the trampling period (Fig. 7). Taxon richness declined with trampling, even though just one of the taxa we specifically recorded showed a trampling effect. In contrast, richness in control transects increased from 7 to more than 9 taxa per quadrat from April to June. Many intertidal organisms reproduce during the winter and spring so this rise in richness may be due to seasonal recruitment (Strathmann 1987). Indeed, it seems likely that both impacts of trampling and rate of recovery vary seasonally. Impacts should be high and persistent when growth and recruitment are low and loss of biomass is not rapidly replaced.

According to our study and others, trampling is likely to result in the following long-term changes. Assemblages will be dominated by turfs rather than foliose algae, which changes habitat for associated species. In areas of chronic or intense trampling these shifts are permanent (Povey and Keough 1991; Keough and Quinn 1998), as are associated threats to native biodiversity. Furthermore, increased bare space can facilitate invasive species (Schiel and Taylor 1999).

The biodiversity of the rocky intertidal zone is one of the major attractants of visitors to parks and reserves, including San Juan County Park. There is a serious risk that recreation could degrade intertidal areas without proper management. People are more likely to appreciate and want to conserve an area to which they have some access; closing all intertidal areas for conservation is not an option that will garner public support. One management option is to establish specific “sacrifice” areas with unlimited public access while restricting access to other areas, protecting them from trampling. Another management option could be to open different areas of the park or reserve shoreline on a rotating schedule to allow for periodic recovery. However, our results show that this recovery may require more time than the initial impact. Finally, the establishment of trails through the intertidal zone, similar to trails found in terrestrial parks and reserves, may increase conservation potential. Paths may improve recovery time because dispersal distance is minimized for organisms from adjacent, undisturbed areas. An enhanced understanding of trampling impacts and recovery ecology in the rocky intertidal will allow for continued public access to the shoreline and preservation of the native habitat through improved management practices.

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Table 1. Repeated measures analysis of variance for canopy cover (arcsine square root transformed) of *Fucus gardneri* recorded in permanent intertidal quadrats from April to August 2000 at San Juan County Park. Impacts of trampling appear in the Time x Treatment interaction.

	df	MS	F	*P*
Block	2	.224	1.568	.230
Treatment (T)	1	1.500	10.489	**.004**
Elevation (E)	2	.126	.882	.427
T x E	2	.337	2.354	.117
Time	4	1.283	26.157	**.000**
Time x Block	8	.134	2.741	**.009**
Time x T	4	.298	6.085	**.000**
Time x E	8	.079	1.608	.133
Time x T x E	8	.034	.694	.696
Residual	92	.049		

Table 2. Repeated measures analysis of variance for Taxon Richness (natural log transformed) recorded in permanent intertidal quadrats from April to August 2000 at San Juan County Park.

	df	MS	F	*P*
Block	2	.036	.544	.588
Treatment (T)	1	.185	2.820	.107
Elevation (E)	2	.186	2.840	.079
T x E	2	.017	.251	.780
Time	4	.121	2.511	**.047**
Time x Block	8	.154	3.180	**.003**
Time x T	4	.185	3.825	**.006**
Time x E	8	.082	1.695	.110
Time x T x E	8	.025	.521	.838
Residual	92	.048		

Table 3. Repeated measures analysis of variance for proportion of bare space (arcsine square root transformed) recorded in permanent intertidal quadrats from April to August 2000 at San Juan County Park.

	df	MS	F	*P*
Block	2	.120	1.241	.308
Treatment (T)	1	.602	6.234	**.020**
Elevation (E)	2	.395	4.094	**.030**
T x E	2	.243	2.511	.103
Time	4	.244	10.016	**.000**
Time x Block	8	.027	1.093	.375
Time x T	4	.045	1.835	.129
Time x E	8	.006	.246	.981
Time x T x E	8	.053	2.174	**.037**
Residual	92	.024		